Score-P – A Joint Performance Measurement Run-Time Infrastructure for Periscope, Scalasca, TAU, and Vampir (continued)

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Scalable performance measurement infrastructure for parallel codes

Congratulations!?

- If you made it this far, you successfully used Score-P to
  - instrument the application
  - analyze its execution with a summary measurement, and
  - examine it with one the interactive analysis report explorer GUIs
- ... revealing the call-path profile annotated with
  - the “Time” metric
  - Visit counts
  - MPI message statistics (bytes sent/received)
- ... but how ***good*** was the measurement?
  - The measured execution produced the desired valid result
  - however, the execution took rather longer than expected!
    - even when ignoring measurement start-up/completion, therefore
    - it was probably dilated by instrumentation/measurement overhead

Performance analysis steps

- 0.0 Reference preparation for validation

- 1.0 Program instrumentation
- 1.1 Summary measurement collection
- 1.2 Summary analysis report examination

- 2.0 Summary experiment scoring
- 2.1 Summary measurement collection with filtering
- 2.2 Filtered summary analysis report examination

- 3.0 Event trace collection
- 3.1 Event trace examination & analysis

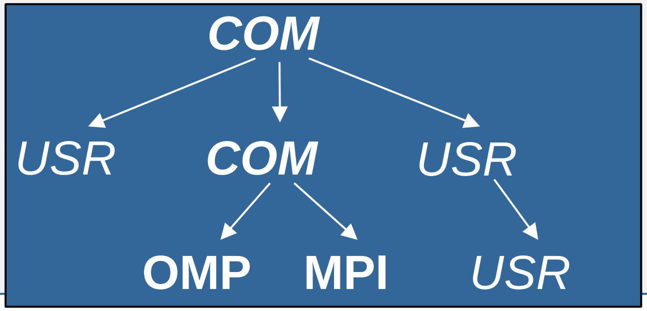
BT-MZ summary analysis result scoring

```
% scorep-score scorep_bt-mz_sum/profile.cubex

Estimated aggregate size of event trace:                   40 GB
Estimated requirements for largest trace buffer (max_buf): 2365 MB
Estimated memory requirements (SCOREP_TOTAL_MEMORY):       2373 MB
(hint: When tracing set SCOREP_TOTAL_MEMORY=2373MB to avoid intermediate flushes
 or reduce requirements using USR regions filters.)

flt     type      max_buf[B]          visits  time[s] time[%] time/visit[us]  region
         ALL   2,479,514,724 1,634,202,275 11031.37   100.0           6.75  ALL
         USR   2,477,923,488 1,631,143,401  4383.44    39.7           2.69  USR
         OMP       4,129,716     2,743,808  4895.09    44.4        1784.05  OMP
         MPI         372,431       128,436  1738.54    15.8       13536.22  MPI
         COM         225,290       186,630    14.30     0.1          76.61  COM
```

40 GB total memory
2.3 GB per rank!

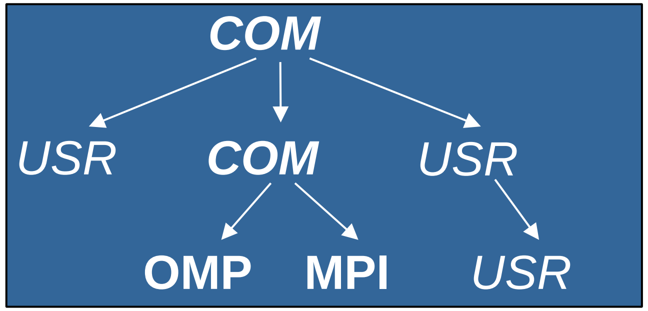


- Report scoring as textual output
- Region/callpath classification
  - **MPI** pure MPI functions
  - **OMP** pure OpenMP regions
  - **USR** user-level computation
  - **COM** “combined” USR+OpenMP/MPI
  - **ANY/ALL** aggregate of all region types

BT-MZ summary analysis report breakdown

```
% scorep-score -r scorep_bt-mz_sum/profile.cubex
  [...]
  [...]
flt type     max_buf[B]        visits  time[s] time[%] time/visit[us]  region
      ALL 2,479,514,724 1,634,202,275 9402.51   100.0            5.75  ALL
      USR 2,477,923,448 1,631,143,401 3694.84    39.3            2.27  USR
      OMP     4,129,716     2,743,808 4200.62    44.7         1530.94  OMP
      MPI       372,430       128,436 1494.89    15.9        11639.21  MPI
      COM       225,290       186,630   12.16     0.1           65.15  COM

      USR   800,074,470   522,844,416  924.44     9.8            1.77  matvec_sub_
      USR   800,074,470   522,844,416 1593.32    16.9            3.05  binvcrhs_
      USR   800,074,470   522,844,416 1030.22    11.0            1.97  matmul_sub_
      USR    26,365,170    22,692,096   60.65     0.6            2.67  lhsinit_
      USR    26,365,170    22,692,096   55.60     0.6            2.45  binvrhs_
      USR    24,964,368    17,219,840   30.58     0.3            1.78  exact_solution_
```



More than
2.2 GB just for these 6
regions

BT-MZ summary analysis score

- Summary measurement analysis score reveals
  - Total size of event trace would be ~40 GB
  - Maximum trace buffer size would be ~2.3 GB per rank
    - smaller buffer would require (unsynchronized) flushes to disk during measurement resulting in substantial perturbation
  - 99.8% of the trace requirements are for USR regions
    - purely computational routines never found on COM call-paths common to communication routines or OpenMP parallel regions
  - These USR regions contribute around 39% of total time
    - however, much of that is very likely to be measurement overhead for frequently-executed small routines
- Advisable to tune measurement configuration
  - Specify an adequate trace buffer size
  - Specify a filter file listing (USR) regions not to be measured

BT-MZ summary analysis report filtering

```
% cat ../config/scorep.filt
SCOREP_REGION_NAMES_BEGIN EXCLUDE
binvcrhs*
matmul_sub*
matvec_sub*
exact_solution*
binvrhs*
lhs*init*
timer_*

% scorep-score -f ../config/scorep.filt -c 2 \
      scorep_bt-mz_sum/profile.cubex

Estimated aggregate size of event trace:                   242 MB
Estimated requirements for largest trace buffer (max_buf):  12 MB
Estimated memory requirements (SCOREP_TOTAL_MEMORY):        20 MB
(hint: When tracing set SCOREP_TOTAL_MEMORY=20MB to avoid \
>intermediate flushes
 or reduce requirements using USR regions filters.)
```

- Report scoring with prospective filter listing 6 USR regions

242 MB of memory in total, 20 MB per rank!

(Including 2 metric values)

BT-MZ summary analysis report filtering

```
% scorep-score -r -f ../config/scorep.filt  scorep_bt-mz_sum/profile.cubex

flt type     max_buf[B]         visits time[s] time[%] time/       region
                                                        visit[us]
 -   ALL 2,479,514,724 1,634,202,275   9402.51   100.0      5.75   ALL
 -   USR 2,477,923,448 1,631,143,401   3694.84    39.3      2.27   USR
 -   OMP     4,129,716     2,743,808   4200.62    44.7   1530.94   OMP
 -   MPI       372,430       128,436   1494.89    15.9  11639.21   MPI
 -   COM       225,290       186,630     12.16     0.1     65.15   COM

 *   ALL     4,732,090     3,064,245   5707.70    60.7   1862.68   ALL-FLT
 +   FLT 2,477,918,768 1,631,138,030   3694.81    39.3      2.27   FLT
 -   OMP     4,129,716     2,743,808   4200.62    44.7   1530.94   OMP-FLT
 -   MPI       372,430       128,436   1494.89    15.9  11639.21   MPI-FLT
 *   COM       225,290       186,630     12.16     0.1     65.15   COM-FLT
 *   USR         4,680         5,371      0.03     0.0      5.59   USR-FLT

 +   USR   800,074,470   522,844,416    924.44     9.8      1.77   matvec_sub_
 +   USR   800,074,470   522,844,416   1593.32    16.9      3.05   binvcrhs_
 +   USR   800,074,470   522,844,416   1030.22    11.0      1.97   matmul_sub_
 +   USR    26,365,170    22,692,096     60.65     0.6      2.67   lhsinit_
 +   USR    26,365,170    22,692,096     55.60     0.6      2.45   binvrhs_
 +   USR    24,964,368    17,219,840     30.58     0.3      1.78   exact_solution_
```

Filtered routines marked with '+'

- Score report breakdown by region

BT-MZ filtered summary measurement

```
% cd bin.scorep
% cp ../jobscript/romeo/scorep.slurm .
% vim scorep.slurm
[…]
export SCOREP_EXPERIMENT_DIRECTORY=scorep_bt-mz_sum_filter
export SCOREP_FILTERING_FILE=../config/scorep.filt
[…]

% sbatch ./scorep.slurm
```

- Set new experiment directory and re-run measurement with new filter configuration

- Submit job

Score-P filtering

```
% cat ../config/scorep.filt
SCOREP_REGION_NAMES_BEGIN
  EXCLUDE
    binvcrhs*
    matmul_sub*
    matvec_sub*
    exact_solution*
    binvrhs*
    lhs*init*
    timer_*
SCOREP_REGION_NAMES_END

% export SCOREP_FILTERING_FILE=\
../config/scorep.filt
```

Region name filter block using wildcards

Apply filter

- Filtering by source file name
  - All regions in files that are excluded by the filter are ignored
- Filtering by region name
  - All regions that are excluded by the filter are ignored
  - Overruled by source file filter for excluded files
- Apply filter by
  - exporting **`SCOREP_FILTERING_FILE`** environment variable
- Apply filter at
  - Run-time
  - Compile-time (GCC-plugin only)
    - Add cmd-line option **`--instrument-filter`**
    - No overhead for filtered regions but recompilation

Source file name filter block

- Keywords
  - Case-sensitive
  - SCOREP_FILE_NAMES_BEGIN, SCOREP_FILE_NAMES_END
    - Define the source file name filter block
    - Block contains EXCLUDE, INCLUDE rules
  - EXCLUDE, INCLUDE rules
    - Followed by one or multiple white-space separated source file names
    - Names can contain bash-like wildcards *, ?, []
    - Unlike bash, * may match a string that contains slashes
- EXCLUDE, INCLUDE rules are applied in sequential order
- Regions in source files that are excluded after all rules are evaluated, get filtered

```
# This is a comment
SCOREP_FILE_NAMES_BEGIN
  # by default, everything is included
  EXCLUDE */foo/bar*
  INCLUDE */filter_test.c
SCOREP_FILE_NAMES_END
```

Region name filter block

- Keywords
  - Case-sensitive
  - `SCOREP_REGION_NAMES_BEGIN`, `SCOREP_REGION_NAMES_END`
    - Define the region name filter block
    - Block contains `EXCLUDE`, `INCLUDE` rules
  - `EXCLUDE`, `INCLUDE` rules
    - Followed by one or multiple white-space separated region names
    - Names can contain bash-like wildcards `*`, `?`, `[]`
- `EXCLUDE`, `INCLUDE` rules are applied in sequential order
- Regions that are excluded after all rules are evaluated, get filtered

```
# This is a comment
SCOREP_REGION_NAMES_BEGIN
  # by default, everything is included
  EXCLUDE *
  INCLUDE bar foo
          baz
          main
SCOREP_REGION_NAMES_END
```

Region name filter block, mangling

- Name mangling
  - Filtering based on names seen by the measurement system
    - Dependent on compiler
    - Actual name may be mangled
- `scorep-score` names as starting point (e.g. `matvec_sub_`)
    - Use `*` for Fortran trailing underscore(s) for portability
    - Use `?` and `*` as needed for full signatures or overloading

```
void bar(int* a) {
    *a++;
}
int main() {
    int i = 42;
    bar(&i);
    return 0;
}
```

```
# filter bar:
# for gcc-plugin, scorep-score
# displays 'void bar(int*)',
# other compilers may differ

SCOREP_REGION_NAMES_BEGIN
  EXCLUDE void?bar(int?)
SCOREP_REGION_NAMES_END
```

Score-P:
Advanced Measurement Configuration

Score-P

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Mastering build systems

- Hooking up the Score-P instrumenter `scorep` into complex build environments like *Autotools* or *CMake* was always challenging
- Score-P provides new convenience wrapper scripts to simplify this (since Score-P 2.0)
- *Autotools* and *CMake* need the used compiler already in the *configure step,* but instrumentation should not happen in this step, only in the *build step*

```
% SCOREP_WRAPPER=off \
> cmake .. \
> -DCMAKE_C_COMPILER=scorep-icc \
> -DCMAKE_CXX_COMPILER=scorep-icpc
```

Disable instrumentation in the *configure step*

Specify the wrapper scripts as the compiler to use

- Allows to pass addition options to the Score-P instrumenter and the compiler via environment variables without modifying the *Makefiles*
- Run `scorep-wrapper --help` for a detailed description and the available wrapper scripts of the Score-P installation

Mastering application memory usage

- Determine the maximum heap usage per process
- Find high frequent small allocation patterns
- Find memory leaks
- Support for:
  - C, C++, MPI, and SHMEM (Fortran only for GNU Compilers)
  - Profile and trace generation (profile recommended)
    - Memory leaks are recorded only in the profile
    - Resulting traces are not supported by Scalasca yet

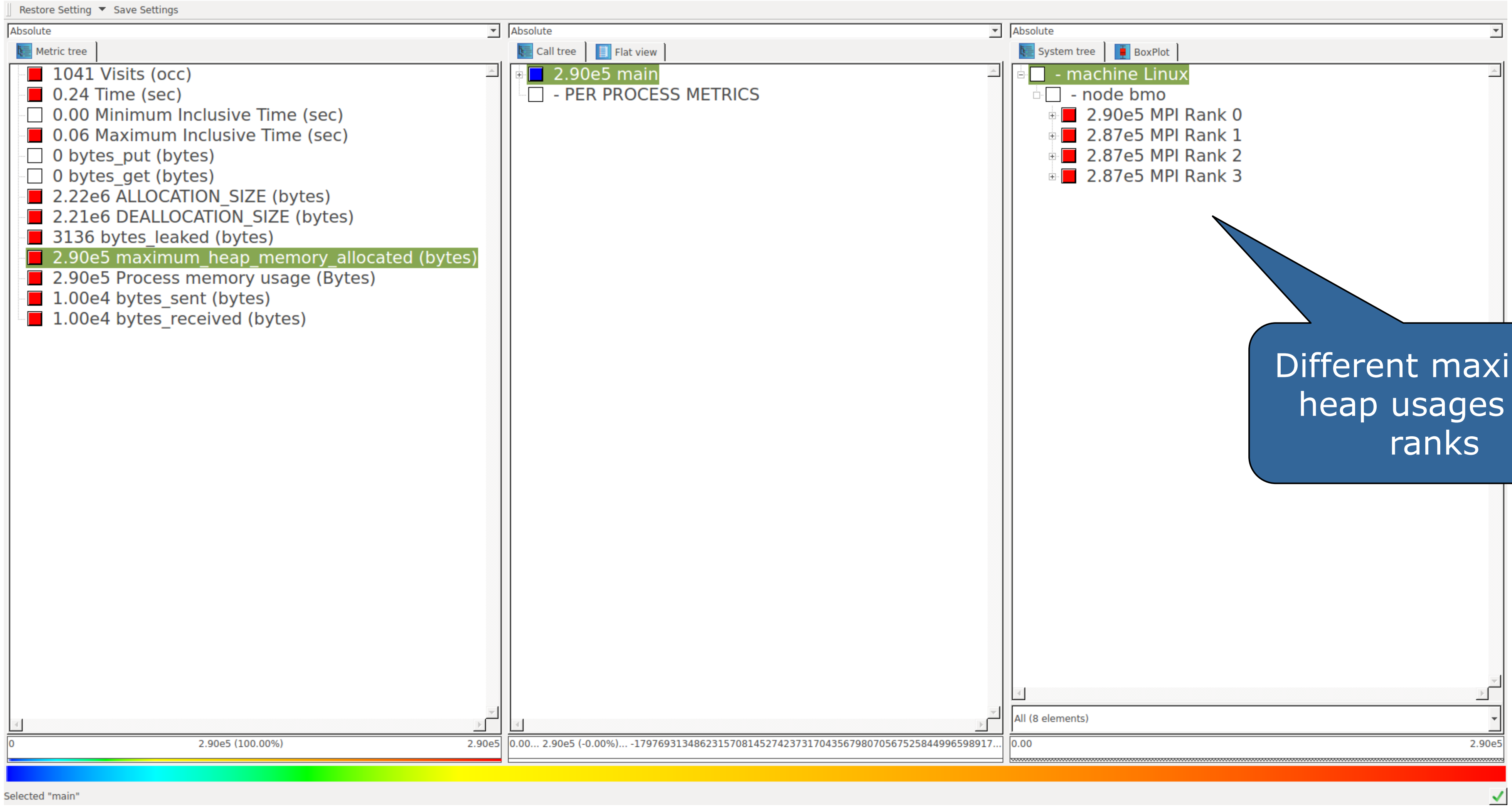
```
% export SCOREP_MEMORY_RECORDING=true
% export SCOREP_MPI_MEMORY_RECORDING=true

% OMP_NUM_THREADS=4 mpiexec –np 4 ./bt-mz_W.4
```

- Set new configuration variable to enable memory recording

- Available since Score-P 2.0

Mastering application memory usage



- 🟥 1041 Visits (occ)
- 🟥 0.24 Time (sec)
- □ 0.00 Minimum Inclusive Time (sec)
- 🟥 0.06 Maximum Inclusive Time (sec)
- □ 0 bytes_put (bytes)
- □ 0 bytes_get (bytes)
- 🟥 2.22e6 ALLOCATION_SIZE (bytes)
- 🟥 2.21e6 DEALLOCATION_SIZE (bytes)
- 🟥 3136 bytes_leaked (bytes)
- 🟥 2.90e5 maximum_heap_memory_allocated (bytes)
- 🟥 2.90e5 Process memory usage (Bytes)
- 🟥 1.00e4 bytes_sent (bytes)
- 🟥 1.00e4 bytes_received (bytes)

Call tree:

- 🟦 2.90e5 main
- □ - PER PROCESS METRICS

System tree:

- □ - machine Linux
  - □ - node bmo
    - 🟥 2.90e5 MPI Rank 0
    - 🟥 2.87e5 MPI Rank 1
    - 🟥 2.87e5 MPI Rank 2
    - 🟥 2.87e5 MPI Rank 3

All (8 elements)

0 2.90e5 (100.00%) 2.90e5

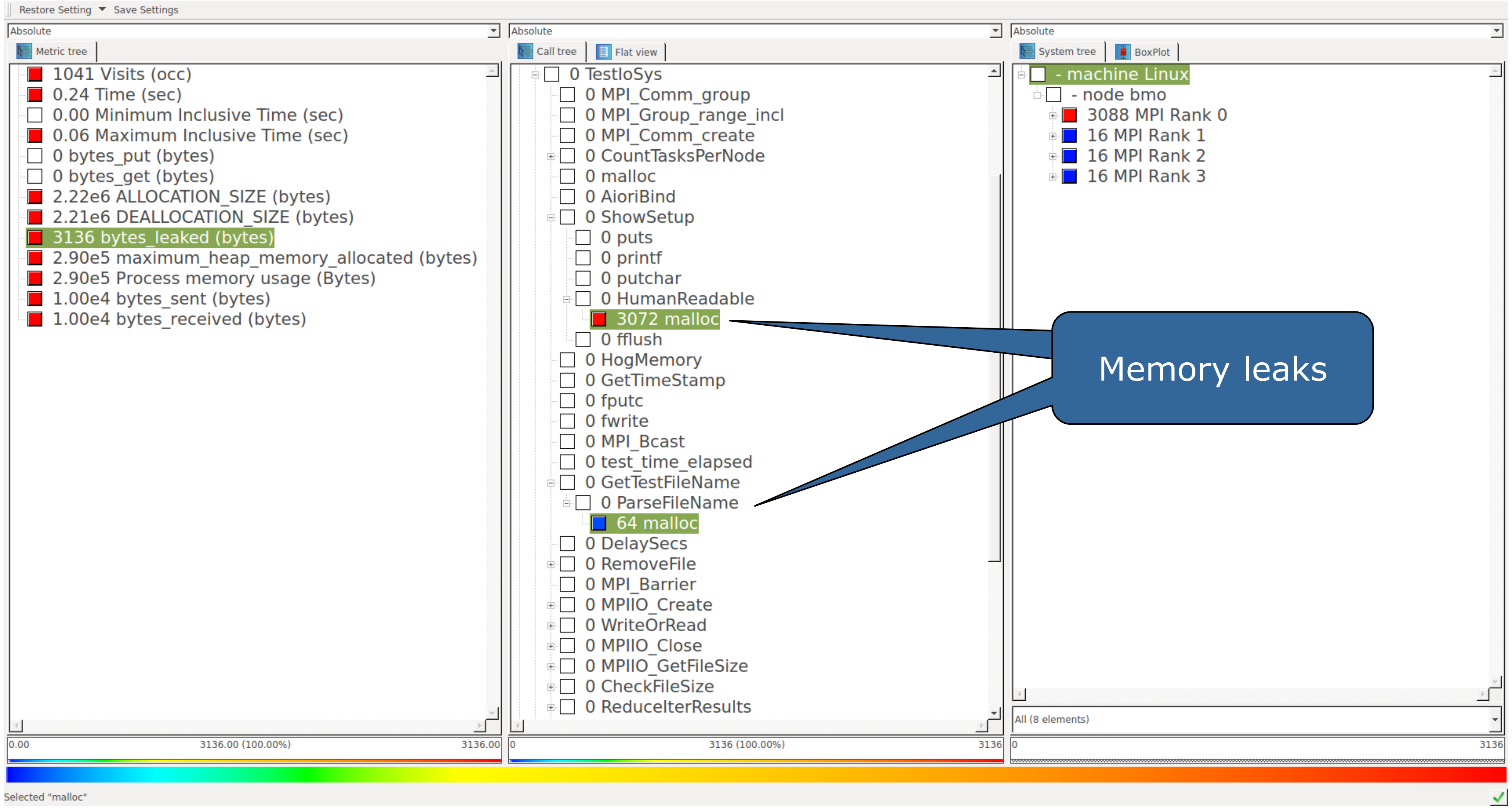
0.00... 2.90e5 (-0.00%)... -179769313486231570814527423731704356798070567525844996598917...

0.00 2.90e5

Selected "main"

Different maximum heap usages per ranks

Mastering application memory usage



🟥 1041 Visits (occ)
🟥 0.24 Time (sec)
□ 0.00 Minimum Inclusive Time (sec)
🟥 0.06 Maximum Inclusive Time (sec)
□ 0 bytes_put (bytes)
□ 0 bytes_get (bytes)
🟥 2.22e6 ALLOCATION_SIZE (bytes)
🟥 2.21e6 DEALLOCATION_SIZE (bytes)
🟥 3136 bytes_leaked (bytes)
🟥 2.90e5 maximum_heap_memory_allocated (bytes)
🟥 2.90e5 Process memory usage (Bytes)
🟥 1.00e4 bytes_sent (bytes)
🟥 1.00e4 bytes_received (bytes)

```
□ 0 TestIoSys
  □ 0 MPI_Comm_group
  □ 0 MPI_Group_range_incl
  □ 0 MPI_Comm_create
  □ 0 CountTasksPerNode
  □ 0 malloc
  □ 0 AioriBind
  □ 0 ShowSetup
    □ 0 puts
    □ 0 printf
    □ 0 putchar
    □ 0 HumanReadable
      🟥 3072 malloc
    □ 0 fflush
  □ 0 HogMemory
  □ 0 GetTimeStamp
  □ 0 fputc
  □ 0 fwrite
  □ 0 MPI_Bcast
  □ 0 test_time_elapsed
  □ 0 GetTestFileName
    □ 0 ParseFileName
      🟦 64 malloc
  □ 0 DelaySecs
  □ 0 RemoveFile
  □ 0 MPI_Barrier
  □ 0 MPIIO_Create
  □ 0 WriteOrRead
  □ 0 MPIIO_Close
  □ 0 MPIIO_GetFileSize
  □ 0 CheckFileSize
  □ 0 ReduceIterResults
```

```
□ - machine Linux
  □ - node bmo
    🟥 3088 MPI Rank 0
    🟦 16 MPI Rank 1
    🟦 16 MPI Rank 2
    🟦 16 MPI Rank 3
```

All (8 elements)

Selected "malloc"

Memory leaks

Advanced measurement configuration: Metrics

- **`SCOREP_METRIC_PAPI=PAPI_TOT_CYC,PAPI_TOT_INS`**
- Available PAPI metrics
  - Preset events: common events deemed relevant and useful for application performance tuning
    - Abstraction from specific hardware performance counters, mapping onto available events done by PAPI internally

```
% papi_avail
```

  - Native events: set of all events that are available on the CPU (platform dependent)

```
% papi_native_avail
```

Note:
Due to hardware restrictions
- number of concurrently recorded events is limited
- there may be invalid combinations of concurrently recorded events

Advanced measurement configuration: Metrics

```
% man getrusage
struct rusage {
    struct timeval ru_utime; /* user CPU time used */
    struct timeval ru_stime; /* system CPU time used */
    long   ru_maxrss;        /* maximum resident set size */
    long   ru_ixrss;         /* integral shared memory size */
    long   ru_idrss;         /* integral unshared data size */
    long   ru_isrss;         /* integral unshared stack size */
    long   ru_minflt;        /* page reclaims (soft page faults)  */
    long   ru_majflt;        /* page faults (hard page faults) */
    long   ru_nswap;         /* swaps */
    long   ru_inblock;       /* block input operations */
    long   ru_oublock;       /* block output operations */
    long   ru_msgsnd;        /* IPC messages sent */
    long   ru_msgrcv;        /* IPC messages received */
    long   ru_nsignals;      /* signals received */
    long   ru_nvcsw;         /* voluntary context switches */
    long   ru_nivcsw;        /* involuntary context switches */
};
```

- **`SCOREP_METRIC_RUSAGE=ru_stime,ru_utime`**
  - `(“all” for complete set)`
- Available resource usage metrics
- Note:

(1) Not all fields are maintained on each platform.

(2) Check scope of metrics (per process vs. per thread)

Score-P user instrumentation API

- Can be used to mark initialization, solver & other phases
  - Annotation macros ignored by default
  - Enabled with [--user] flag
- Appear as additional regions in analyses
  - Distinguishes performance of important phase from rest
- Can be of various type
  - E.g., function, loop, phase
  - See user manual for details
- Available for Fortran / C / C++

Score-P user instrumentation API (Fortran)

```
#include "scorep/SCOREP_User.inc"

subroutine foo(…)
  ! Declarations
  SCOREP_USER_REGION_DEFINE( solve )

  ! Some code…
  SCOREP_USER_REGION_BEGIN( solve, “<solver>", \
                            SCOREP_USER_REGION_TYPE_LOOP )
  do i=1,100
    [...]
  end do
  SCOREP_USER_REGION_END( solve )
  ! Some more code…
end subroutine
```

- Requires processing by the C preprocessor

Score-P user instrumentation API (C/C++)

```
#include "scorep/SCOREP_User.h"

void foo()
{
  /* Declarations */
  SCOREP_USER_REGION_DEFINE( solve )

  /* Some code… */
  SCOREP_USER_REGION_BEGIN( solve, “<solver>",
                            SCOREP_USER_REGION_TYPE_LOOP )
  for (i = 0; i < 100; i++)
  {
    [...]
  }
  SCOREP_USER_REGION_END( solve )
  /* Some more code… */
}
```

Score-P user instrumentation API (C++)

```
#include "scorep/SCOREP_User.h"

void foo()
{
  // Declarations

  // Some code…
  {
    SCOREP_USER_REGION( “<solver>",
                        SCOREP_USER_REGION_TYPE_LOOP )
    for (i = 0; i < 100; i++)
    {
      [...]
    }
  }
  // Some more code…
}
```

Score-P measurement control API

- Can be used to temporarily disable measurement for certain intervals
  - Annotation macros ignored by default
  - Enabled with [--user] flag

```
#include “scorep/SCOREP_User.inc”

subroutine foo(…)
  ! Some code…
  SCOREP_RECORDING_OFF()
  ! Loop will not be measured
  do i=1,100
    [...]
  end do
  SCOREP_RECORDING_ON()
  ! Some more code…
end subroutine
```

Fortran (requires C preprocessor)

```
#include “scorep/SCOREP_User.h”

void foo(…) {
  /* Some code… */
  SCOREP_RECORDING_OFF()
  /* Loop will not be measured */
  for (i = 0; i < 100; i++) {
    [...]
  }
  SCOREP_RECORDING_ON()
  /* Some more code… */
}
```

C / C++

Further information

- Community instrumentation & measurement infrastructure
  - Instrumentation (various methods)
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data
- Available under 3-clause BSD open-source license
- Documentation & Sources:
  - http://www.score-p.org
- User guide also part of installation:
  - `<prefix>/share/doc/scorep/{pdf,html}/`
- Support and feedback: support@score-p.org
- Subscribe to news@score-p.org, to be kept informed